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Assessing changes in selected Geotechinical properties of clay soil contaminated with diesel oil

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Abstract

This research work studied the impact of diesel oil contamination on the geotechnical properties of clay soil, which is crucial for understanding how such contamination can affect soil behavior in construction and environmental contexts. A series of tests were conducted to analyze key properties, including liquid limit (LL), plastic limit (PL), plasticity index (PI), specific gravity, bulk density, maximum dry density (MDD), and optimum moisture content (OMC) across various levels of diesel contamination. The findings reveal significant changes in the soil's characteristics due to diesel contamination. As the level of contamination increases, both the LL and PL of the clay soil rise markedly. The liquid limit increased from 31% in uncontaminated soil to 56% at 14% diesel contamination, while the plastic limit similarly rose from 20% to 41% across the same contamination range. This indicates that diesel oil increases the soil's plasticity, making it more deformable under pressure. In contrast, other properties like specific gravity and bulk density showed a decline with increasing diesel contamination. Specific gravity, which reflects the soil's density, decreased significantly from 2.48 at 0% contamination to 1.14 at 14%. Bulk density also decreased, highlighting how diesel's lower density affects the overall structure of the soil. The maximum dry density (MDD) also declined, suggesting that diesel oil makes it more challenging to compact the soil effectively. Overall, the study underscores the pronounced influence of diesel oil on the engineering properties of clay soil. These changes have important implications for construction and environmental management in areas affected by diesel contamination, emphasizing the need for careful consideration of soil properties in such scenarios.

Keywords: Clay soil; Diesel; Geotechinical Properties; Oil spillage

1. Introduction

Environmental degradation in Nigeria and other oil-producing countries worldwide has been significantly driven by the activities of multinational companies involved in oil exploration, production, storage, and transportation. These operations are often associated with oil spills, which can occur accidentally during transportation—both on land and sea—due to leaks from corroded pipelines, damaged storage tanks, or during drilling processes (Talakdar and Serika, 2013). In many instances, these spills result in large pools of oil that cover extensive areas and may not be promptly cleaned, leading to soil contamination. This contamination alters the soil's composition and affects its physical and chemical properties, with the extent of these changes depending on the specific composition and quantity of hydrocarbons released.

The Niger Delta region of Nigeria, which contains the majority of the country's oil wells, has been heavily impacted by widespread oil pollution. Between 1976 and 1991, there were 4,647 reported incidents of oil spills in the Niger Delta, leading to the release of approximately 2,369,470 barrels of oil (Badejo and Nwilo, 2013). Additionally, the illegal

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siphoning of fuel, driven by the black market for fuel products, has increased the frequency of oil pipeline explosions in recent years (Hashim, 2013).

While the discovery of oil in Nigeria has brought economic prosperity, it has also had severe environmental consequences for oil-producing communities. The geotechnical properties of soil are crucial in determining its suitability for construction and other engineering applications. Clay soils, in particular, are widely studied due to their unique behavior under varying environmental conditions. However, these properties can be significantly altered by contaminants such as diesel oil, a common pollutant in industrial and urban areas. Diesel contamination often arises from leaks and spills associated with storage tanks, pipelines, and machinery, posing potential risks to soil stability and the structural integrity of buildings and infrastructure.

The impact of such spills cannot be underestimated, as they induce changes in the engineering properties and behavior of soils. These changes have profound implications for existing and proposed structures supported by contaminated soil. Functional and structural failures may occur, especially when contamination leads to significant changes in soil plasticity, loss of bearing capacity, increased settlement, and reduced permeability (Osinubi et al., 2007).

Understanding the influence of diesel oil on clay soil is vital for engineers and environmental scientists. Diesel oil, as a hydrocarbon, can interact with the soil's mineralogical components, resulting in changes to key geotechnical properties such as the liquid limit, plastic limit, plasticity index, specific gravity, bulk density, maximum dry density, and optimum moisture content. These properties are essential for assessing soil load-bearing capacity, compaction behavior, and overall stability, which are critical considerations in construction and environmental remediation efforts.

This study aims to explore how varying levels of diesel oil contamination affect the geotechnical properties of clay soil. Through a series of controlled experiments, this research seeks to quantify the changes in these properties and provide insights into their implications for construction practices and environmental management. The findings are expected to improve the understanding of the risks associated with diesel-contaminated soils and to guide strategies for mitigating these risks in engineering and environmental contexts.

2. Materials and Method

2.1. Materials

The soil samples utilized in this study were collected from an oil spill site located in the Akiogbologbo community within the Engenni, Ahoada West Local Government Area of Rivers State, in the Niger Delta region of Nigeria. This area is part of the tropical rainforest vegetation zone and is geographically positioned at approximately 4° 42’ N latitude and 7° 21’ E longitude. The region's lithology is characterized predominantly by alluvial soils, which are typical of the Niger Delta.

2.2. Methods

Soil samples were obtained from various depths ranging between 1 to 3 meters, which were considered to be the maximum depth of oil contaminant infiltration. The level of diesel contamination in each sample was quantified as a percentage of the weight of dry, uncontaminated soil. The samples were then divided into eight groups, with diesel oil added to create contamination levels of 2%, 4%, 6%, 8%, 10%, 12%, and 14%, while one group with 0% contamination served as the control.

To ensure consistency, the samples were mixed with water matching the soil's natural moisture content. They were then stored in sealed containers and allowed to age for three weeks, ensuring thorough mixing and uniformity across the samples. After this aging period, the samples were transported to the Soil Mechanics Laboratory at the Federal University of Technology, Owerri (FUTO), where they underwent a series of geotechnical tests. These tests included Atterberg limits, bulk density, specific gravity, and Proctor compaction tests, all conducted following the ASTM standard methods of measurement.

3. Results and Discussions

3.1. Effect of Diesel Oil on Atterberg Limits of Clay Soil

The LL, PL, and PI for both contaminated and uncontaminated clay soil samples at varying diesel contamination levels are illustrated in Figures 1, 2, and 3. The data clearly demonstrate that the introduction of diesel oil significantly influences the index properties of the soils tested. Specifically, the liquid limit of clay soil contaminated with diesel oil progressively rose from 30% at zero percent contamination to 55% at 14% contamination. Similarly, the plastic limit (PL) rose from 20% at 0 percent contamination to 40% at 14% contamination. Correspondingly, the plasticity index (PI) also increased from 11% at zero% contamination to 15% at 14% contamination

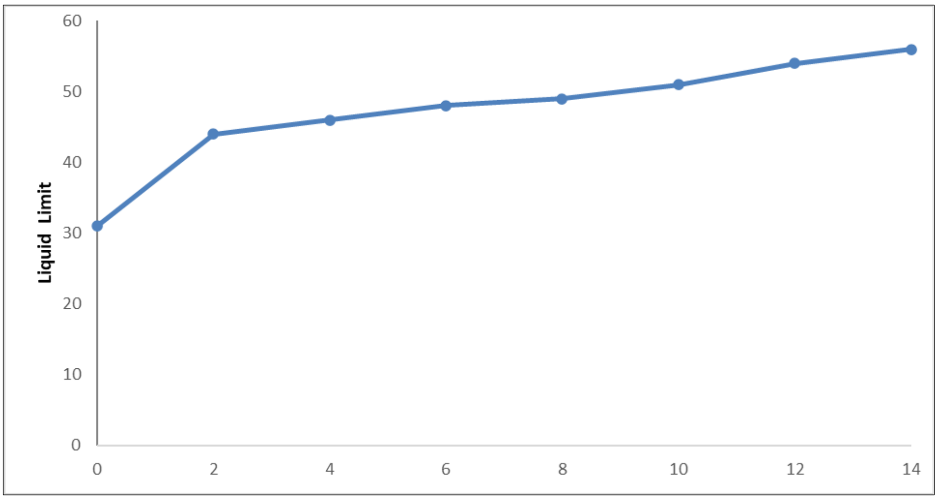

Figure 1 Graph of Liquid Limit (LL) of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel

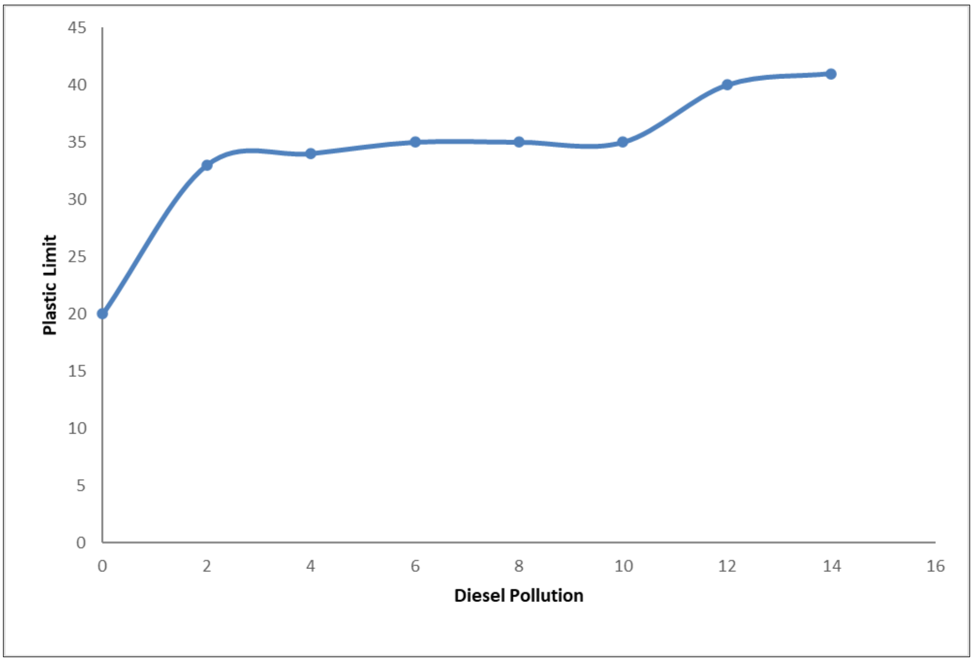

Figure 2 Graph of Plastic Limit (PL) of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel

The increase in these index properties can be attributed to the dipolar nature of water molecules, which possess both positive and negative charges. These dipolar molecules are attracted to the negatively charged surfaces of clay particles and the cations within the double layer. Furthermore, hydrogen atoms in the water molecules form hydrogen bonds with oxygen atoms in the clay particles. This results in the formation of what is known as double-layer water, which is tightly bound to the clay particles, thereby imparting plastic properties to the soil. On the other hand, the free water in the soil, which is not absorbed by the clay particles and can move freely, determines the soil's liquid behavior (Das, 1994). Diesel oil coats the clay particles, preventing water molecules from accessing the double layer, which requires more water for the soil to attain its plastic properties. This is likely the reason for the observed increase in the index properties.

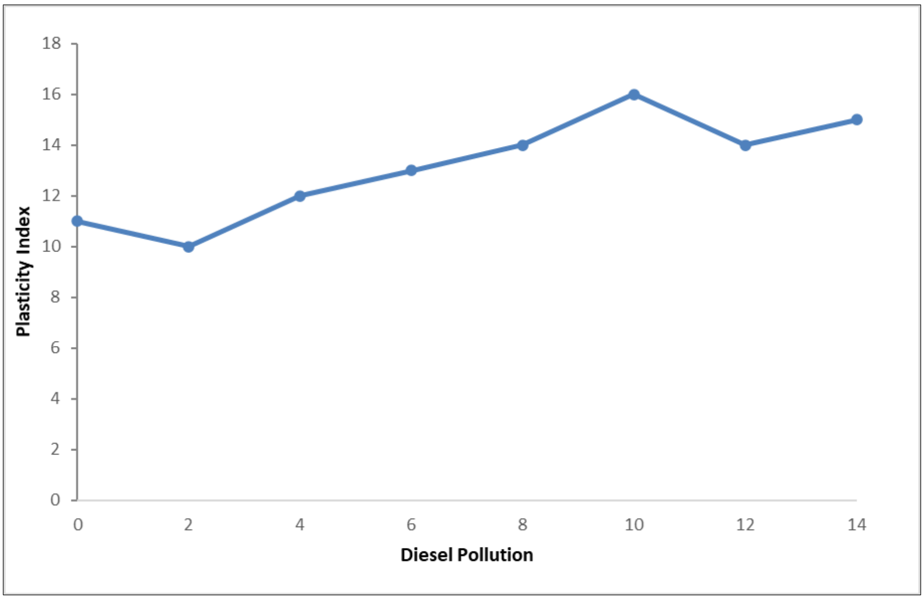

Figure 3 Graph of Plasticity Index (PI) of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel

3.2. Effect of Diesel Oil on Specific Gravity of Clay Soil

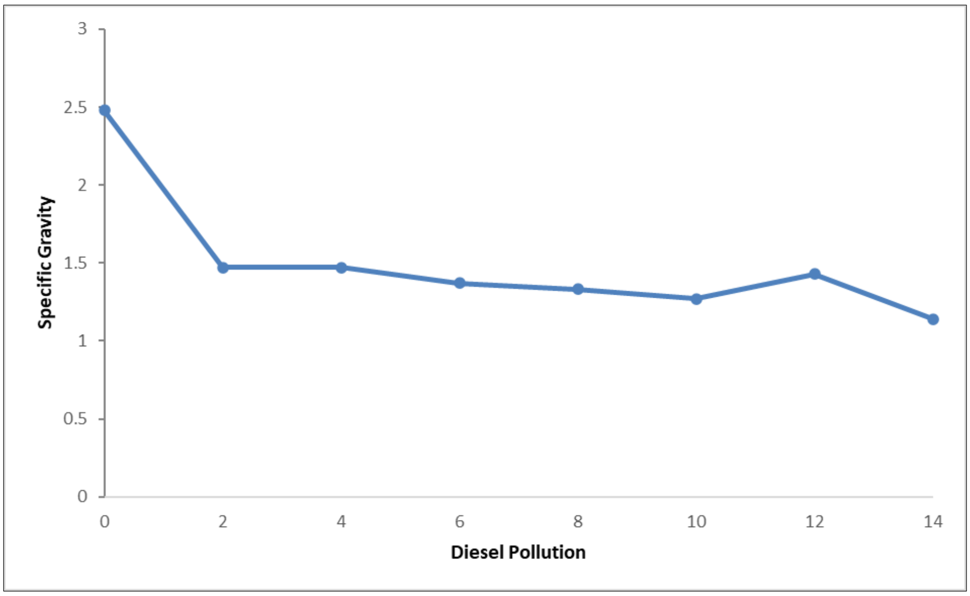

Figure 4 Graph of Specific Gravity of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel

The specific gravity of the clay soil decreased significantly, from 2.48 at 0% contamination to 1.14 at 14% contamination, representing a reduction of approximately 54%. This decrease can be ascribe to the lower specific gravity of diesel oil compared to clay, which reduces the overall specific gravity of the contaminated soil. Refer to Figure 4 for the data.

3.3. Effect of Diesel Oil on Bulk Density of Clay Soil

As depicted in Figure 5, the bulk density of the diesel-contaminated clay soil decreased from 1.33 g/cm^3 at 0% contamination to 0.97 g/cm^3 at 14% contamination, reflecting a reduction of about 27%. This decline in bulk density is likely due to the introduction of diesel oil, which lowers the bulk density of the soil.

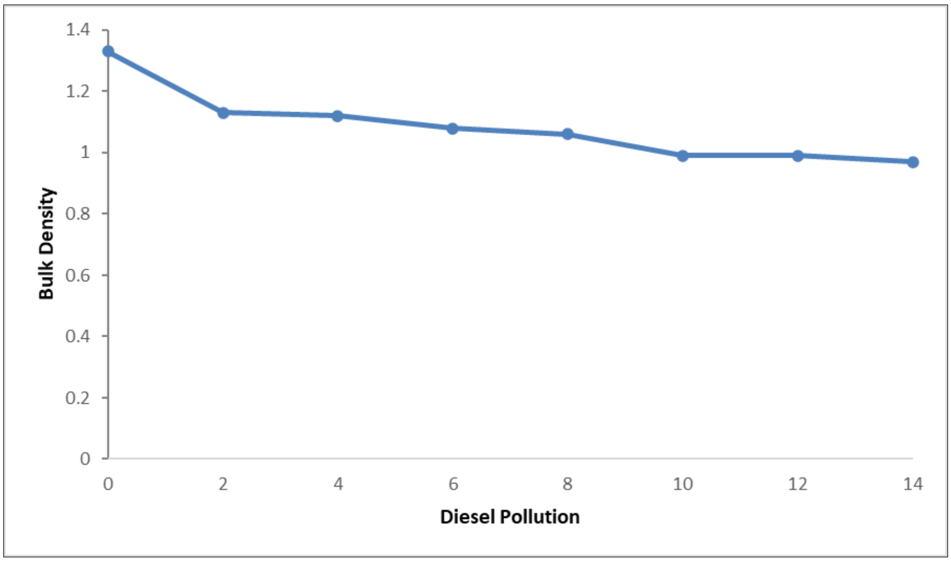

Figure 5 Graph of BD of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel Oil

3.4. Effect of Diesel Oil on Maximum Dry Density of Clay Soil

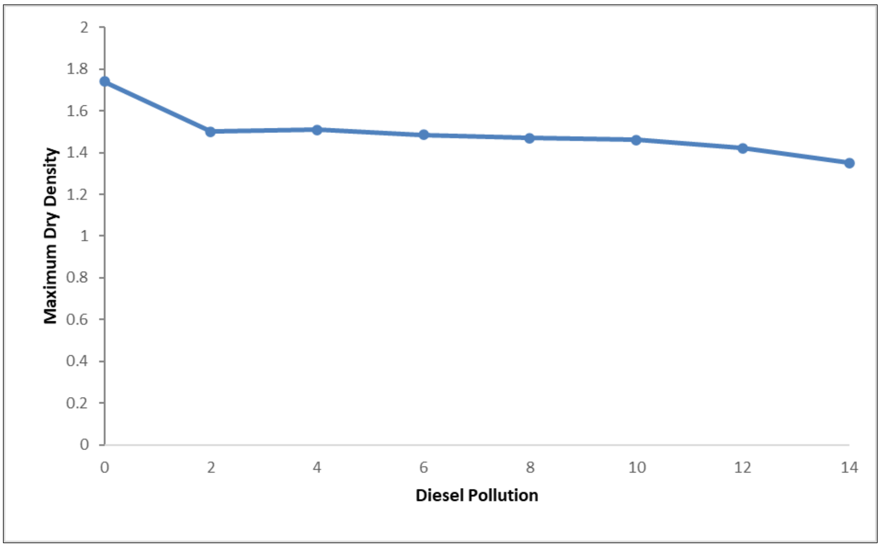

Figure 6 Graph of MDD of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel

The results of the Proctor compaction test, shown in Figures 6, indicate that the maximum dry density (MDD) of diesel-contaminated clay decreased from 1.5 g/cm^3 at 0% contamination to 1.33 g/cm^3 at 14% contamination, representing a 10% reduction. This decrease in MDD may be due to the expansion of the diffuse double layer, which hinders effective soil compaction. As a result, when the same compaction energy is applied, uncontaminated soil exhibits a higher MDD compared to contaminated soil, which has a less dense particle arrangement. This reduction in MDD could also be influenced by the lubricating effect of diesel oil, which decreases the soil's compactability. Moreover, the inherent strength of the soil, allowing it to achieve only a minimal MDD, may also contribute to this reduction. These findings align with the research of Pandey and Bind (2014).

3.5. Effect of Diesel Oil on Optimum Moisture Content of Clay Soil

In the case of clay soil contaminated with diesel, the OMC increased from 15% at 0% contamination to 19.3% at 6% contamination before gradually decreasing, although it did not drop below 16%. Refer to Figure 7, as well as Figure 4.18 and Table A19 in the Appendix, for further details. The observed decrease at higher diesel concentrations is likely due to the partial occupation of inter-particle spaces by diesel, which alters the soil structure, making it looser than uncontaminated soil (Zulfahmi et al., 2010).

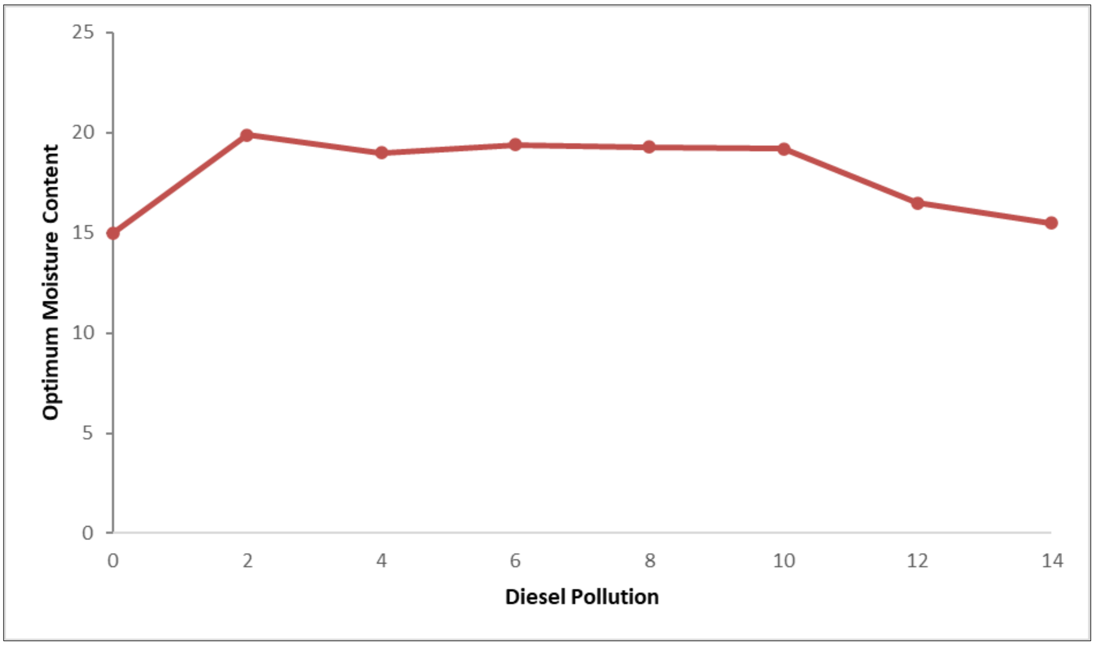

Figure 7 Graph of OMC of Diesel-Contaminated Clay Soil Against Different Concentrations of Diesel

4. Conclusion

This study has demonstrated that diesel oil contamination significantly alters the geotechnical properties of clay soil. The observed increase in the liquid limit and plastic limit, coupled with the decrease in specific gravity, bulk density, and maximum dry density, indicates that diesel oil contamination has a profound impact on the soil's physical and mechanical behavior. These changes suggest that diesel-contaminated clay soils become more plastic and less dense, making them less suitable for construction purposes without appropriate remediation.

The findings underscore the necessity of considering contamination effects in geotechnical assessments, especially in regions where soil contamination by diesel or similar hydrocarbons is likely. Future construction projects on such soils should account for the altered properties to avoid potential structural issues. Additionally, this study highlights the importance of remediation strategies to restore or improve the geotechnical characteristics of contaminated soils, ensuring safety and stability in construction and environmental applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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